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(54) **Title:** METHOD AND APPARATUS FOR LOCATING A MOBILE DEVICE WITHOUT SYNCHRONIZING BASE STATION CLOCKS

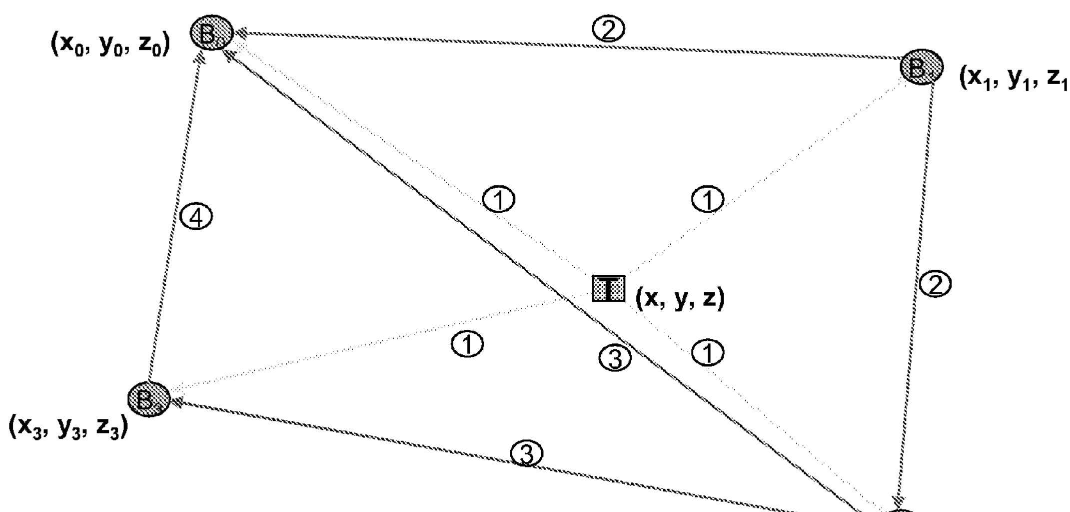

FIG. 6

(57) **Abstract:** A time difference of arrival computation is used to determine the location of a mobile device relative to a set of base stations at known locations without synchronizing local clocks at the base stations via a technique called "clock correction." In accordance with this method, the reception time of a timing signal generated by the mobile device relative to a local clock at each base station is sent via messages to one of the base stations which corrects the reception time relative to its own local clock. Trilateration is then used with the corrected timing signals in order to determine the location of the mobile device.

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METHOD AND APPARATUS FOR LOCATING A MOBILE DEVICE WITHOUT SYNCHRONIZING BASE STATION CLOCKS

BACKGROUND

[0001] “Wireless” devices can take any of a number of forms, including cellular telephones and pagers, as well as various types of Internet, Web, or other network enabled devices, such as personal digital assistants (PDAs). Generally, a wireless device configured for transmitting, receiving, accessing, or exchanging data via a network may be referred to as a "mobile device" and communications between mobile devices may be referred to as "wireless communications".

[0002] In many situations, it is necessary to monitor the location or position of the mobile device in a given localized area. The position may be of interest for security reasons in order to prevent unauthorized devices located outside of the area from using the network or for other reasons. Typically, position detection and motion tracking of such devices involve signal timing analysis, such as time of arrival (TOA) or time difference of arrival (TDOA) based measurements, such as those used by global positioning systems (GPS) that involve measuring the timing of signals between the mobile device and a set of geo-stationary satellites. However, often GPS techniques cannot be used indoors or underground due to signal unavailability, interference and signal multi-path effects.

[0003] Therefore, detection and location of a mobile device within a defined indoor local area is typically performed using a local area network (LAN) comprised of a set of "base stations" which communicate wirelessly with the mobile device. If the geographical location of each base station is known, the location of the wireless device can be determined by a variety of techniques. For example, received signal strength indicator (RSSI) values may be obtained from the communications between the wireless device and the base stations. The RSSI values of signals between the mobile device and a particular base station vary depending on the distance between the mobile device and that base station. If there are at least three base stations that receive signals from the wireless device, the location of the device can be determined by a well-known process of trilateration. However, location systems that use RSSI techniques are generally relatively imprecise due to a number of factors, such as signal interference and multi-path signals.

[0004] It is also possible to use TOA and TDOA techniques with the signals that pass between the mobile device and the base stations. In this case, the time of arrival of signals generated by the mobile device is measured at each base station relative to a local clock in that base station. Then, all of the timing signals are sent to a central location where trilateration methods are used to determine the location of the mobile device. However, these methods require that the local clocks in the base stations be synchronized relative to each other. This synchronization, in turn, requires additional communications between the devices and between the base stations which adds to the communication burden.

SUMMARY

[0005] In accordance with the principles of the invention, TDOA techniques are used to determine the location of a mobile device relative to a set of base stations at known locations without synchronizing the local clocks via a technique called "clock correction." In accordance with this method, the reception time of a timing signal generated by the mobile device relative to a local clock at each base station is sent via messages to one of the base stations which corrects the reception time relative to its own local clock. Trilateration is then used with the corrected timing signals in order to determine the location of the mobile device.

[0006] In another embodiment, a calibration method is used to compensate for local clock drift between the time that the timing signal generated by the mobile device is received and the time that the message is sent to the base station.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] Figure 1 is a schematic diagram showing the basic layout of the various components of the mobile device locating system.

[0008] Figure 2 is a schematic diagram illustrating clock correction between stations.

[0009] Figure 3 is a schematic diagram illustrating local clock drift.

[0010] Figure 4 is a schematic diagram for compensating for clock drift by calibration.

[0011] Figure 5 is a schematic diagram illustrating the process of deriving a clock correction using a clock relational factor derived form a calibration.

[0012] Figure 6 is a schematic diagram illustrating an alternative embodiment using distributed computations.

[0013] Figure 7 is a time line showing the signal timing in the embodiment illustrated in Figure 6.

[0014] Figure 8 is a block schematic illustration of an embodiment in which the base stations are wirelessly connected.

[0015] Figure 9 is a block schematic illustration of the components in a base station.

[0016] Figure 10 is a block schematic illustration of an embodiment in which the base stations are connected by a LAN or WAN network.

DETAILED DESCRIPTION

[0017] Figure 1 shows the basic layout of the various components of the mobile device locating system. As shown four base stations (B_0, B_1, B_2, B_3) are used, although more or less base stations can be used as long as at least three base stations are present. The geographical position (x_i, y_i, z_i) of each base station device B_i is known in advance. The mobile device Tag (T) is moving and, thus, its position (x, y, z) is not known in advance. Each device (B_0, B_1, B_2, B_3 and Tag) in the positioning system runs its own internal clock. In order to determine, the location of the Tag (T), the Tag is instructed by one of the base stations (for example, the closest base station) to generate a timing signal. This timing signal is sent to all base stations as indicated by the transmission signals (1) in Figure 1. Each base station records the time of arrival of this timing signals relative to its local clock and then sends this time of arrival encoded in a signal to a pre-selected base station (in this example, base station B_0) as indicated by transmissions 2, 3 and 4. Base station B_0 then determines the geographical position of the Tag (T).

[0018] Figure 2 illustrates the concept of clock correction. In this figure, two base stations A and B are located at fixed positions with a distance d_0 separating them. Base station B sends a message to base station A. The message contains a coded value representing the value of the local clock in station B at the time the message is sent. In the figure, the value t_s^B denotes the time at which the first signal of the message is sent from base station B as determined by the local clock of base station B. The value t_r^A denotes the time at which the first signal of the message is received at node A as determined by the local clock of base station A. Assuming that the local clock of base station A is faster than the local clock of base station B, then, the difference between the two clock values (denoted as ck_{A_B} in Figure 2) is given by the following equation:

$$ck_{A-B} = (t_r^A - t_s^B) - \frac{d_0}{c} \qquad (1)$$

where c is the speed of light.

[0019] Using equation (1) the location process proceeds as follows. Assume that $d_0[1]$ is the physical distance between base stations B_0 and B_1, $d_0[2]$ is the physical distance between base stations B_0 and B_2 and $d_0[3]$ is the physical distance between base stations B_0 and B_3 respectively and that $d_0[1]$, $d_0[2]$ and $d_0[3]$ are known in advance. Assume further that ck_0, ck_1, ck_2 and ck_3 are the local clocks in base stations B_0, B_1, B_2 and B_3, respectively and that clock ck_0 is the fastest clock.

[0020] Then, from the broadcast of the timing signals from the tag shown as signals (1) in Figure 1, the base stations B_0, B_1, B_2 and B_3 each get the time of arrival values of the timing signal from the tag as determined by their local clocks (ck_0, ck_1, ck_2 and ck_3). These values are denoted as tt_0^0, tt_1^1,tt_2^2 and tt_3^3, respectively.

[0021] Next, base stations B_1, B_2 and B_3 send messages containing these values and the times at which the messages are sent to base station B_0. From the communication between B_1 and B_0 (denoted as signal (2) in Figure 1), base station B_0 obtains from the message from B_1 the time the tag signal is received at station B_1 (tt_1^1) and the time that the message is sent from B_1 to B_0 (denoted as t_{s1}^1). Station B_0 also records the time of arrival of the message as determined with its local clock ck_0 , which is denoted as t_{r1}^0. Then, with equation (1) as set forth above, station B_0 calculates the time of arrival of the timing signal from the Tag to station B_1 relative to the station B_0 clock ck_0 as the following:

$$tt_1^0 = tt_1^1 + ck_{0\_1} = tt_1^1 + ((t_{r1}^0 - t_{s1}^1) - \frac{d_0[1]}{c})$$

[0022] From the communication between B_2 and B_0 (denoted as signal (3) in Figure 1), base station B_0 obtains from the message from B_2 the time the tag signal is received at station B_2 (tt_2^2) and the time that the message is sent from B_2 to B_0 (denoted as t_{s2}^2). Station B_0 also records the time of arrival of the message as determined with its local clock ck_0 , which is denoted as t_{r2}^0. Then, with equation (1) as set forth above, station B_0 calculates the time of arrival of the timing signal from the Tag to station B_2 relative to the station B_0 clock ck_0 as the following:

$$tt_2^0 = tt_2^2 + ck_{0\_2} = tt_2^2 + ((t_{r2}^0 - t_{s2}^2) - \frac{d_0[2]}{c})$$

[0023] In a similar manner, from the communication between B_3 and B_0 (denoted as signal (4) in Figure 1), base station B_0 calculates the time of arrival of the timing signal from the Tag to station B_3 relative to the station B_0 clock ck_0 as the following:

$$tt_3^0 = tt_3^3 + ck_{0\_3} = tt_3^3 + ((t_{r3}^0 - t_{s3}^3) - \frac{d_0[3]}{c})$$

[0024] Using the calculated times of arrival relative to the local clock ck_0 of the timing signal sent by the Tag at the four base-stations (denoted as tt_0^0, tt_1^0,tt_2^0, tt_3^0 from the previous equations) and the known coordinates of the four base-stations B_0, B_1, B_2 and B_3, station B_0 calculates the position (*x, y, z*) of the mobile Tag by solving the following equations:

$$\left|tt_1^0 - tt_0^0\right| \times c = \left|\sqrt{(x-x_1)^2+(y-y_1)^2+(z-z_1)^2} - \sqrt{(x-x_0)^2+(y-y_0)^2+(z-z_0)^2}\right|$$

$$\left|tt_2^0 - tt_0^0\right| \times c = \left|\sqrt{(x-x_2)^2+(y-y_2)^2+(z-z_2)^2} - \sqrt{(x-x_0)^2+(y-y_0)^2+(z-z_0)^2}\right|$$

$$\left|tt_3^0 - tt_0^0\right| \times c = \left|\sqrt{(x-x_3)^2+(y-y_3)^2+(z-z_3)^2} - \sqrt{(x-x_0)^2+(y-y_0)^2+(z-z_0)^2}\right|$$

[0025] The aforementioned calculation assumes that the local clock in each base station is stable during the time interval between the time that timing signal is received from the Tag and the time at which a message is sent to the base station B_0. However, in general, this is not the case. Figure 3 shows a typical case. Here a timing signal is sent from the Tag at time t0 as indicated by arrow 300. It arrives at base station B_1 at time t1. Some time later, after a delay of duration L that depends on the internal configuration of the base station B_1 and/or an intentional delay, a message is sent at time t2 to base station B_0 as indicated by arrow 302. Here, t0, t1 and t2 are absolute times.

[0026] If the local clock ck_1 in base station B_1 were perfect, then t2 would be equal to t1 + L. However, during the time period L, drift in the local clock ck_1 results in the clock value t2 at the end of L period being equal to t1 + L + Δ where Δ is the drift in the clock value during the time period L. In order to make the location calculation accurate, the corrected clock value at the beginning of the L period is needed, but, in the process described previously, what is computed is the corrected clock value at the end of the L time period. Without correcting for this drift, the positioning error of the inventive location system will be in the same order as conventional two-way ranging based IPS (TRIPS).

[0027] The clock drift can be compensated by calibration. This process is illustrated in Figure 4. Here base station A sends a message of length L to base station B. This would be done before operation of the system begins and may also be done periodically during operation to adjust the compensation. The values t_1^A and t_2^A are the values of a counter in base station A, which correspond to the time of transmitting the start of the message and the time of transmitting the end of the message, respectively. The values t_1^B and t_2^B are the values of a counter in base station B, which correspond to the time of receiving the beginning of the message and the time of receiving the end of the message, respectively. The values t_{cyc_A} and t_{cyc_B} denote the duration of one cycle of the clock in base station A and base station B, respectively. Then

$$\frac{d}{c} = (t_1^B \times t_{cyc\_B} - t_1^A \times t_{cyc\_A}) \text{ and}$$

$$\frac{d}{c} = (t_2^B \times t_{cyc\_B} - t_2^A \times t_{cyc\_A})$$

[0028] Given these two equations, the relationship η between the two clocks in base station A and base station B is given by:

$$\eta = \frac{t_{cyc\_A}}{t_{cyc\_B}} = \frac{t_2^B - t_1^B}{t_2^A - t_1^A}$$

[0029] Using the clock relationship η, the clock corrections between the base station B_0 and the other base stations can be compensated for drift as shown in Figure 5. Here base station B_1 sends a calibration message to base station B_0 before operation of the system begins. This message is used to determine the value of η as set forth above. Then, the mobile device (Tag) sends a timing message to station B_1

which is received at time tt_1^1. Base station B_1 then sends a message to station B_0 at time t_{s1}^1. The time at which the timing signal arrives at station B_1, as determined relative to the local clock at station B_0 and corrected for drift in the clock at station B_1 ($tt_{r\_tt1}^0$) is given by:

$$tt_{r\_tt1}^0 = t_{r1}^0 - (t_{s1}^1 - tt_1^1) \times \eta$$

where t_{r1}^0 is the time that the message from station B_1 is actually received at station B_0. This gives a clock correction for the reception of the timing signal at station B_1 relative to the local clock at station B_0 of:

$$ck_{tt1} = (tt_{r\_tt1}^0 - tt_1^1) - \frac{d}{c} = ((t_{r1}^0 - (t_{s1}^1 - tt_1^1) \times \eta) - tt_1^1) - \frac{d}{c}$$

[0030] Using the correction factor η the aforementioned location process is modified as follows. Again, assume that $d_0[1]$ is the physical distance between base stations B_0 and B_1, $d_0[2]$ is the physical distance between base stations B_0 and B_2 and $d_0[3]$ is the physical distance between base stations B_0 and B_3 respectively and that $d_0[1]$, $d_0[2]$ and $d_0[3]$ are known in advance. Assume further that ck_0, ck_1, ck_2 and ck_3 are the local clocks in base stations B_0, B_1, B_2 and B_3, respectively and that clock ck_0 is the fastest clock.

[0031] Then, from the broadcast of the timing signals from the tag shown as signals (1) in Figure 1, the base stations B_0, B_1, B_2 and B_3 each get the time of arrival values of the timing signal from the tag as determined by their local clocks (ck_0, ck_1, ck_2 and ck_3). These values are denoted as tt_0^0, tt_1^1,tt_2^2 and tt_3^3, respectively.

[0032] Next, base stations B_1, B_2 and B_3 send messages containing these values and the times at which the messages are sent to base station B_0. From the communication between B_1 and B_0 (denoted as signal (2) in Figure 1), base station B_0 obtains from the message from B_1 the time the tag signal is received at station B_1 (tt_1^1) and the time that the message is sent from B_1 to B_0 (denoted as t_{s1}^1). Station B_0 also records the time of arrival of the message as determined with its local clock ck_0 , which is denoted as t_{r1}^0. Then, with equation (1) as set forth above, station B_0 calculates the time of arrival of the timing signal from the Tag to station B_1 relative to the station B_0 clock ck_0 as the following:

$$tt_1^0 = tt_1^1 + ck_{0\_1} = tt_1^1 + \{((t_{r1}^0 - (t_{s1}^1 - tt_1^1) \times \eta_{0\_1}) - tt_1^1) - \frac{d_0[1]}{c}\}$$

[0033] From the communication between B_2 and B_0 (denoted as signal (3) in Figure 1), base station B_0 obtains from the message from B_2 the time the tag signal is received at station B_2 (tt_2^2) and the time that the message is sent from B_2 to B_0 (denoted as t_{s2}^2). Station B_0 also records the time of arrival of the message as determined with its local clock ck_0 , which is denoted as t_{r2}^0. Then, with equation (1) as set forth above, station B_0 calculates the time of arrival of the timing signal from the Tag to station B_2 relative to the station B_0 clock ck_0 as the following:

$$tt_2^0 = tt_2^2 + ck_{0\_2} = tt_2^2 + \{((t_{r2}^0 - (t_{s2}^2 - tt_2^2) \times \eta_{0\_2}) - tt_2^2) - \frac{d_0[2]}{c}\}$$

[0034] In a similar manner, from the communication between B_3 and B_0 (denoted as signal (4) in Figure 1), base station B_0 calculates the time of arrival of the timing signal from the Tag to station B_3 relative to the station B_0 clock ck_0 as the following:

$$tt_3^0 = tt_3^3 + ck_{0\_3} = tt_3^3 + \{((t_{r3}^0 - (t_{s3}^3 - tt_3^3) \times \eta_{0\_3}) - tt_3^3) - \frac{d_0[3]}{c}\}$$

[0035] Using the calculated times of arrival relative to the local clock ck_0 of the timing signal sent by the Tag at the four base-stations (denoted as tt_0^0, tt_1^0,tt_2^0, tt_3^0 from the previous equations) and the known coordinates of the four base-stations B_0, B_1, B_2

and B_3, station B_0 can calculate the position (*x, y, z*) of the mobile Tag by solving the above equations.

[0036] The aforementioned location arrangement requires station B_0 to make all of the positioning calculations. It is also possible to decentralize the calculations using the signal transmissions shown on Figure 6. The time line for the transmissions is shown in Figure 7. At time T0 the mobile device (Tag) transmits the timing signal to all stations as indicated as transmissions (1) in Figure 6. Then, at time T1 stations B0, B1 B2, B3 receive the timing signals (1) At time T1' station B1 sends a message to stations B0 and B2 as indicated by signal (2) in Figure 6. At time T2, stations B0 and B2 receive the message (2) from station B1. Subsequently, at time T2' station B2 sends a message to stations B0 and B3 as indicated in Figure 6 by signal (3). At time T3 stations B0 and B3 receive the message from station B2. Next, at time T3' station B3 sends a message to station B0 shown as signal (4) in Figure 6. Finally, at time T4, station B0 receives the message (4) from station B3. This arrangement allows some of the calculations to be performed at stations B2 and B3 as well as station B0.

[0037] The aforementioned arrangement has some significant advantages. For example, it is based on one-way ranging. Therefore, compared with conventional two-way ranging, the inventive location arrangement saves bandwidth. More specifically, at least six communications are needed between stations for positioning via two-way ranging – three two-way communications between the mobile device and three base-stations. However, with one-way based positioning, only four communications between the mobile device and the base stations are needed.

[0038] In addition, there is no requirement to synchronize the local clocks in the base stations, because the local clocks are used to measure the relative time of arrival.

[0039] The inventive arrangement also saves power in the mobile device both because only one transmission from the mobile device is required and also because the position computation is performed at the base stations rather than the mobile device. The arrangement is also reliable for a dynamic radio environment, because the three base-stations i.e. B1, B2, B3, are used as references, which correct the measurement error in real time.

[0040] Further, since the time between the reception of the timing signal in a station and the transmission of a message concerning that timing signal from that station (the time duration L) is adjustable. It is possible to adjust this time to prevent signal overlap of the relayed signals.

[0041] Figure 8 shows a block schematic illustration of an embodiment 800 in which all of the base stations 802-808 are wirelessly connected as shown schematically by arrows 810-814. In this embodiment, each base station may be a wireless access point and base station 802 constitutes the pre-selected base station that performs the location calculations.

[0042] Figure 9 is a block schematic diagram of the components of a base station 900, which might be the pre-selected base station 802 or, in the case where computations are distributed among the base stations as discussed above, any of the other base stations 804-808. Base station 900 includes a transceiver 904 which is connected to the antenna 902 to both receive and transmit wireless signals between the mobile unit and other base stations. Transceiver 904 is connected to a timing unit 910, which is also connected to the local clock 914. Timing unit 910 determines the time of arrival relative to local clock 914 by detecting the start of a timing signal received by transceiver 902 from the mobile unit or the start of a message received from another base station.

[0043] Messages received from the mobile unit or other base stations are placed in message buffer 906 by the transceiver 904. A message decoder 908 processes the messages in buffer 906 in order to extract the timing information as discussed above. The time of arrival information generated by timing unit 910 and the timing information in incoming messages, which is extracted by message decoder 908, are provided to computation unit 912 which, in the case of the pre-selected base station, determines the location of the mobile unit as discussed above. In the case of other base stations, computation unit 912 may generate message to be sent to the pre-selected base station with timing information as discussed above. These message are placed in the message buffer 906 for transmission by the transceiver 904.

[0044] Figure 10 is a block schematic illustration of another embodiment 1000 in which the base stations 1002-1008 are connected by a network 1010, which could be a LAN or a WAN, such as the Internet. Embodiment 1000 eliminates the need for the base stations to communicate wirelessly.

[0045] While the invention has been shown and described with reference to a number of embodiments thereof, it will be recognized by those skilled in the art that various changes in form and detail may be made herein without departing from the spirit and scope of the invention as defined by the appended claims.

[0046] What is claimed is:

Claims

1. A method for determining the location of a mobile device relative to a plurality of base stations, wherein the physical locations of, and distances between, the base stations are known and each base station has a local clock, the method comprising:

(a) at each base station, receiving a timing signal broadcast by the mobile device and determining a time of arrival (TOA) of the timing signal relative to a local clock at that base station;

(b) at each base station except a pre-selected base station, transmitting to the pre-selected base station a message including the TOA determined in step (a) and a sending time at which the message was sent relative to the local clock at that base station;

(c) at the pre-selected base station, receiving each message, determining the message reception time relative to a pre-selected base station local clock and correcting the TOA included in that message relative to the pre-selected base station local clock based on the message reception time, the sending time included in that message and a known distance between the pre-selected base station and the base station which sent that message; and

(d) determining the location of the mobile device using a trilateration method with the corrected TOAs and the physical locations of the base stations.

2. The method of claim 1 wherein the sending time in step (b) is a time at which a first signal of the message is sent relative to the local clock at that base station.

3. The method of claim 1 wherein step (c) comprises determining a clock difference between the pre-selected base station local clock and the local clock of the base station that sent the message by subtracting a transit time of the message from

the difference of the message reception time and the message sending time and using the clock difference to correct the TOA included in the message.

4. The method of claim 1 wherein the location of the mobile device is determined using a time difference of arrival trilateration method with differences between the TOAs as corrected at the pre-selected base station.

5. The method of claim 1 further comprising:

(e) before step (a) determining a correction factor for drift in the local clock at each base station, which drift occurs between the TOA of the timing signal and the message sending time.

6. The method of claim 5 wherein step (c) comprises correcting the TOA included in that message relative to the pre-selected base station local clock based on the sending time included in that message, a known distance between the pre-selected base station and the base station which sent that message and the correction factor determined in step (e).

7. The method of claim 5 wherein step (e) comprises:

(e1) sending a calibration signal having a duration relative to the pre-selected base station local clock from the pre-selected base station to each other base station;

(e2) at each other base station, receiving a calibration signal, determining the duration of the calibration signal relative to the local clock at that base station and sending to the pre-selected base station a message including the duration of the calibration signal relative to the local clock at that base station; and

(e3) at the pre-selected base station, determining the correction factor for a base station from a quotient of the duration relative to the pre-selected base station local clock of a calibration signal sent to that base station and a calibration signal duration received in a message from that base station.

8. The method of claim 1 wherein step (c) comprises determining the TOA included in that message relative to the pre-selected base station local clock (tt_1^0) using the formula $tt_1^0 = tt_1^1 + ((t_{r1}^0 - t_{s1}^1) - \frac{d_0[1]}{c})$ where tt_1^1 is the time of arrival of the timing signal at the other base station relative to the other base station local clock, t_{r1}^0 is the message reception time at the pre-selected base station, t_{s1}^1 is the message sending time included in that message, $d_0[1]$ is the distance between the pre-selected base station and the other base station and c is the speed of light.

9. Apparatus for determining the location of a mobile device relative to a plurality of base stations, wherein the physical locations of, and distances between, the base stations are known, wherein:

each base station except a pre-selected base station comprises a local clock, a transceiver that receives a timing signal broadcast by the mobile device, a timing unit that determines a time of arrival (TOA) of the timing signal relative to the base station local clock and a computation unit that transmits to a pre-selected base station a message including the TOA determined by the timing unit and a sending time at which the message was sent relative to the local clock; and wherein

the pre-selected base station comprises a local clock, a transceiver that receives each message, a timing unit that determines the message reception time relative to the pre-selected base station local clock and a computation unit that corrects the TOA included in that message relative to the pre-selected base station local clock based on the message reception time, the sending time included in that message and a known distance between the pre-selected base station and the base station which sent that message and a computation unit that determines the location of the mobile device using a trilateration method with the corrected TOAs and the physical locations of the base stations.

10. The apparatus of claim 9 wherein the sending time in the message that a computation unit in a base station transmits to the pre-selected base station comprises a time at which a first signal of the message was sent relative to the base station local clock.

11. The apparatus of claim 9 wherein the computation unit in the pre-selected base station includes a mechanism that determines a clock difference between the pre-selected base station local clock and the local clock of the base station that sent a message by subtracting a transit time of the message from the difference of the message reception time and the message sending time and a mechanism that uses the clock difference to correct the TOA included in the message.

12. The apparatus of claim 9 wherein the computation unit in the pre-selected base station determines a location of the mobile device using a time difference of arrival trilateration method with differences between the TOAs as corrected at the pre-selected base station.

13. The apparatus of claim 9 further comprising a correction mechanism at the pre-selected base station that determines a correction factor for drift in the local clock at each base station, which drift occurs between the TOA of the timing signal and the message sending time.

14. The apparatus of claim 13 wherein the computation unit in the pre-selected base station comprises a mechanism that corrects the TOA included in a message arriving from another base station based on the sending time included in that message, a known distance between the pre-selected base station and the base

station which sent that message and the correction factor determined by the correction mechanism.

15. The apparatus of claim 13 wherein the correction mechanism comprises:

a mechanism that sends a calibration signal having a duration relative to the pre-selected base station local clock from the pre-selected base station to each other base station,

a mechanism at each other base station, that receives the calibration signal, determines the duration of the calibration signal relative to the local clock at that base station and sends to the pre-selected base station a message including the duration of the calibration signal relative to the local clock at that base station; and

a computational unit at the pre-selected base station that determines the correction factor for a base station from a quotient of the duration relative to the pre-selected base station local clock of a calibration signal sent to that base station and a calibration signal duration received in a message from that base station.

16. The apparatus of claim 9 wherein the computation unit in the pre-selected base station comprises a mechanism that determines a TOA of the timing signal included in a message relative to the pre-selected base station local clock (tt_1^0) using the formula $tt_1^0 = tt_1^1 + ((t_{r1}^0 - t_{s1}^1) - \frac{d_0[1]}{c})$ where tt_1^1 is the time of arrival of the timing signal at the other base station relative to the other base station local clock, t_{r1}^0 is the message reception time at the pre-selected base station, t_{s1}^1 is the message sending time included in that message, $d_0[1]$ is the distance between the pre-selected base station and the other base station and c is the speed of light.

17. The apparatus of claim 9 wherein the transceivers in the base stations communicate wirelessly with the transceiver in the pre-selected base station.

18. The apparatus of claim 9 wherein the transceivers in the base stations communicate with the transceiver in the pre-selected base station over a network.

19. The apparatus of claim 18 wherein the network comprises one of a LAN and a WAN.

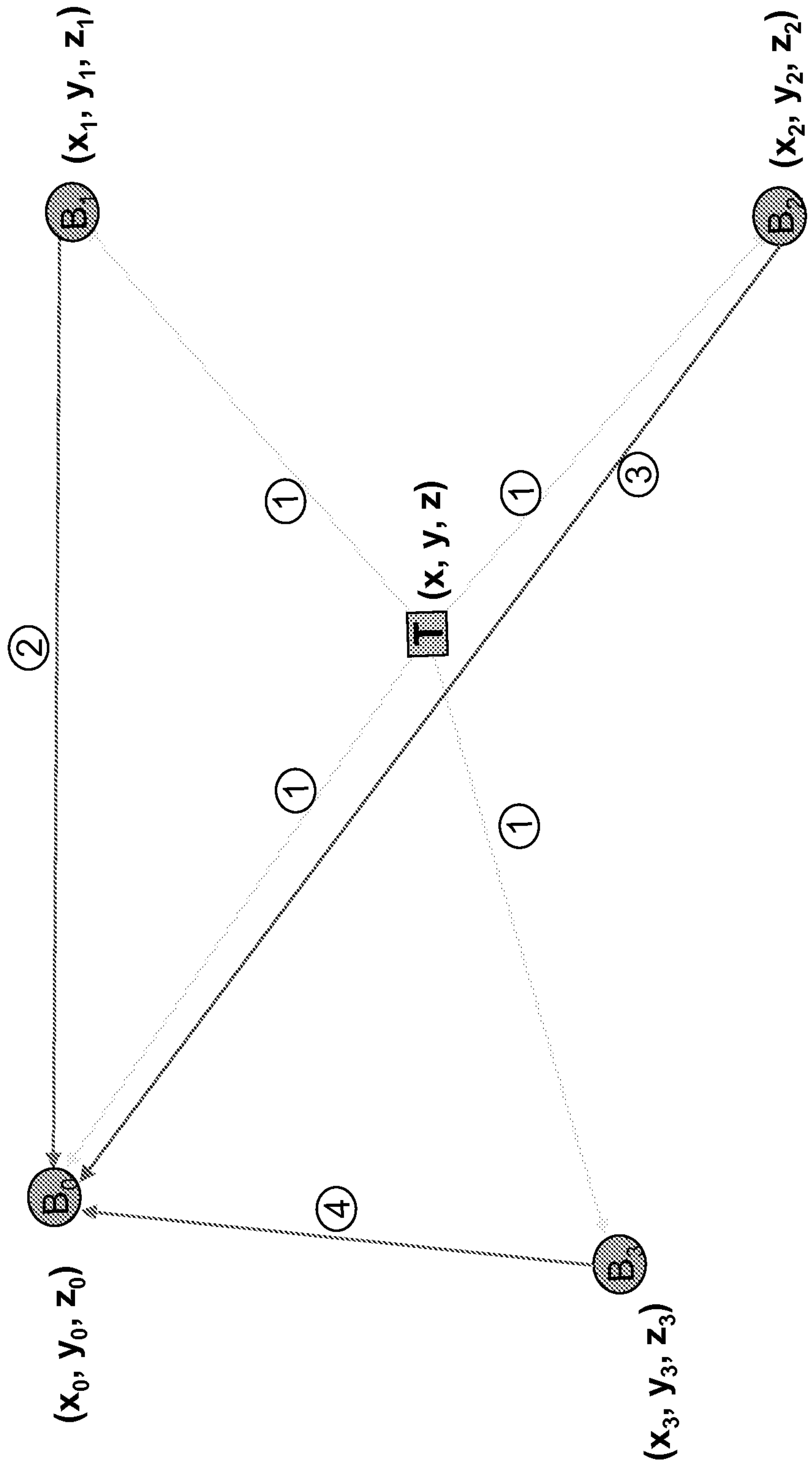


FIG. 1

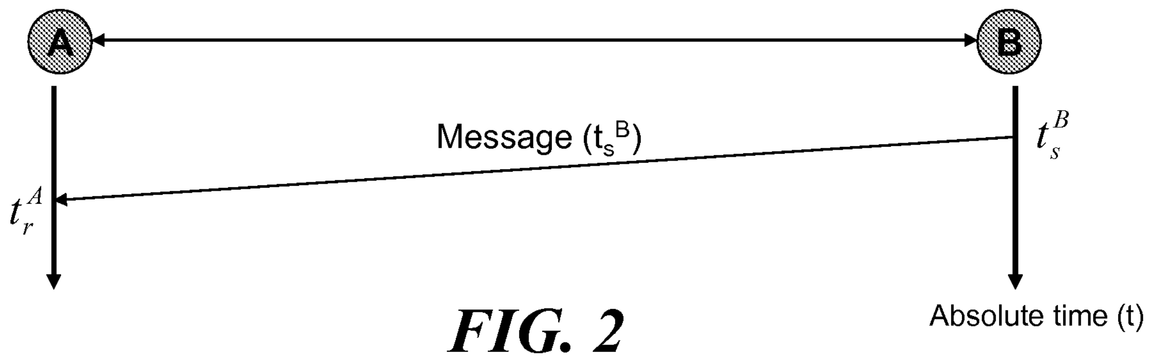

A
B
Message (t_s^B)
t_s^B
t_r^A
Absolute time (t)

FIG. 2

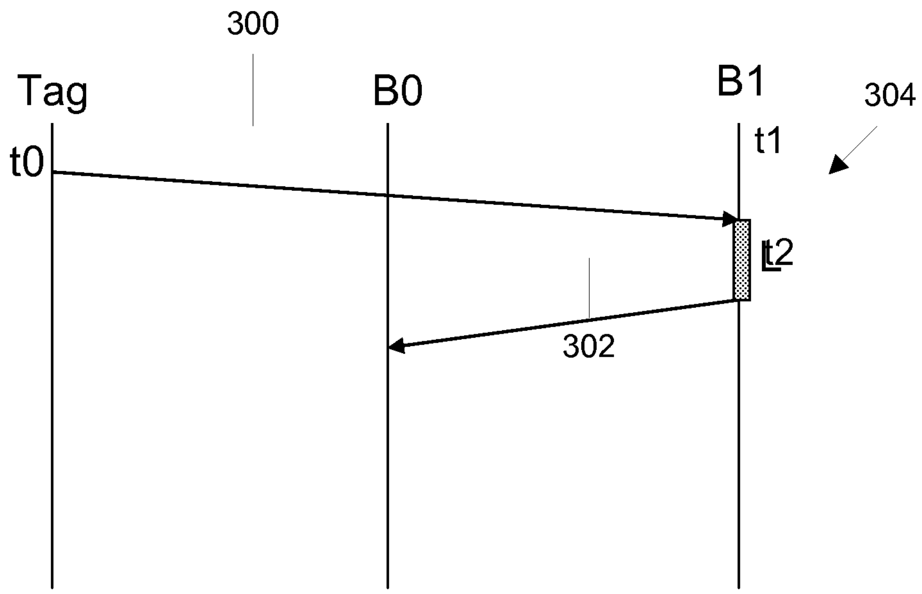

300
Tag
B0
B1
304
t1
t0
t2
302

FIG. 3

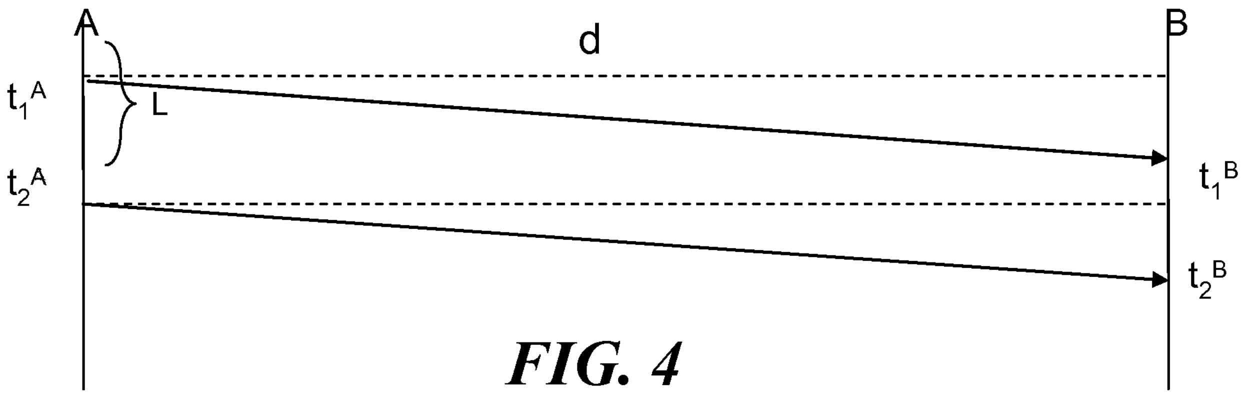

A
B
d
L
t_1^A
t_2^A
t_1^B
t_2^B

FIG. 4

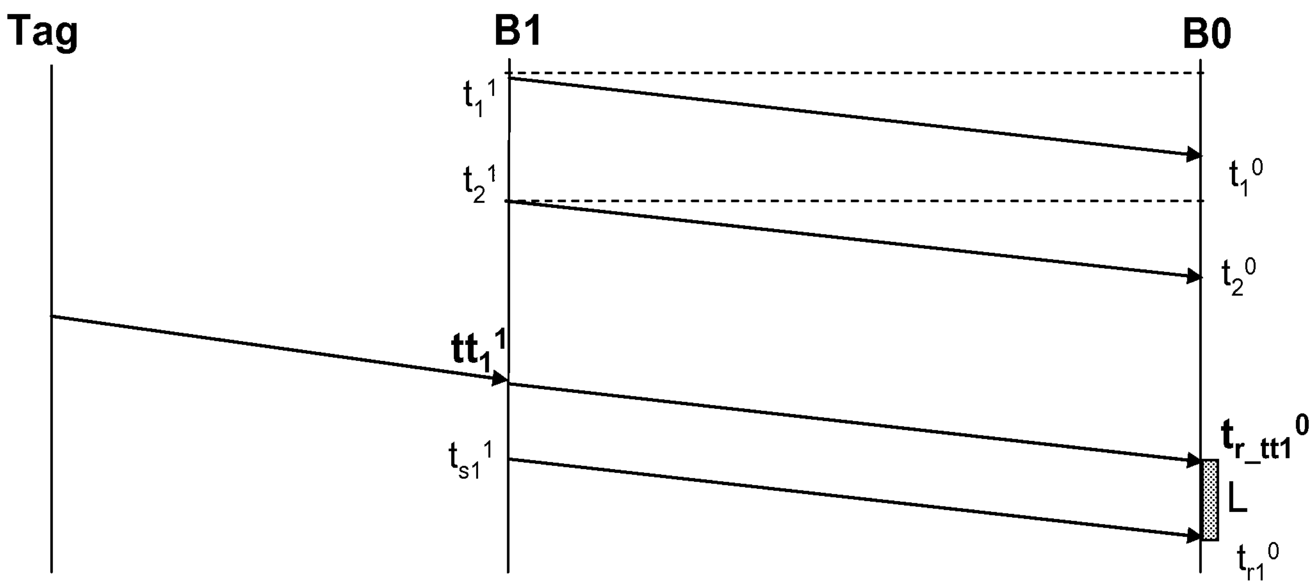
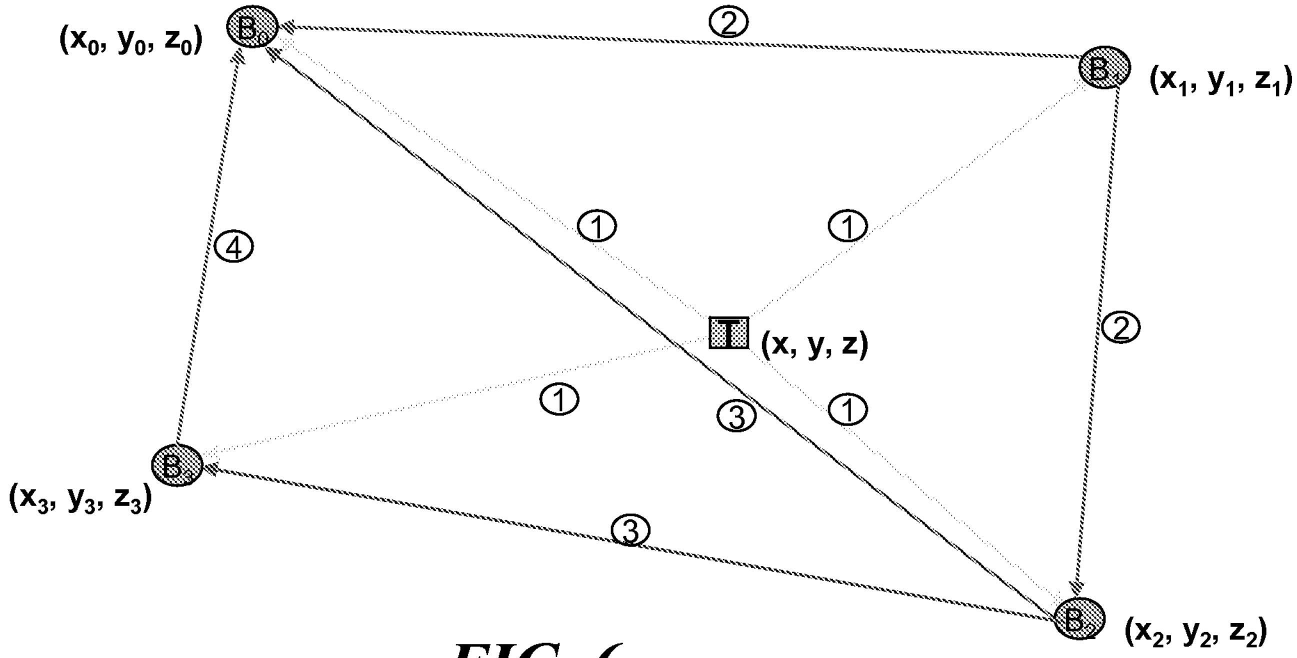
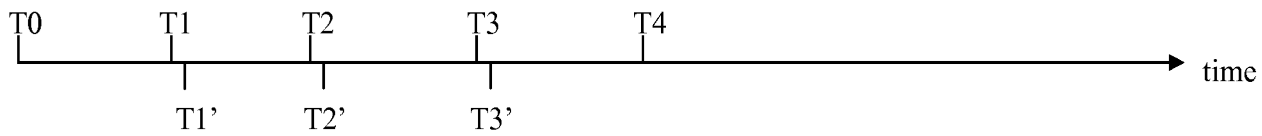

Tag
B1
B0
t_1^1
t_2^1
t_1^0
t_2^0
tt_1^1
t_{s1}^1
$t_{r\_tt1}^0$
L
t_{r1}^0

FIG. 5



B
(x0, y0, z0)
2
B
(x1, y1, z1)
1
1
4
2
T
(x, y, z)
1
3
1
B
(x3, y3, z3)
3
B
(x2, y2, z2)

FIG. 6



T0
T1
T2
T3
T4
time
T1'
T2'
T3'

FIG. 7

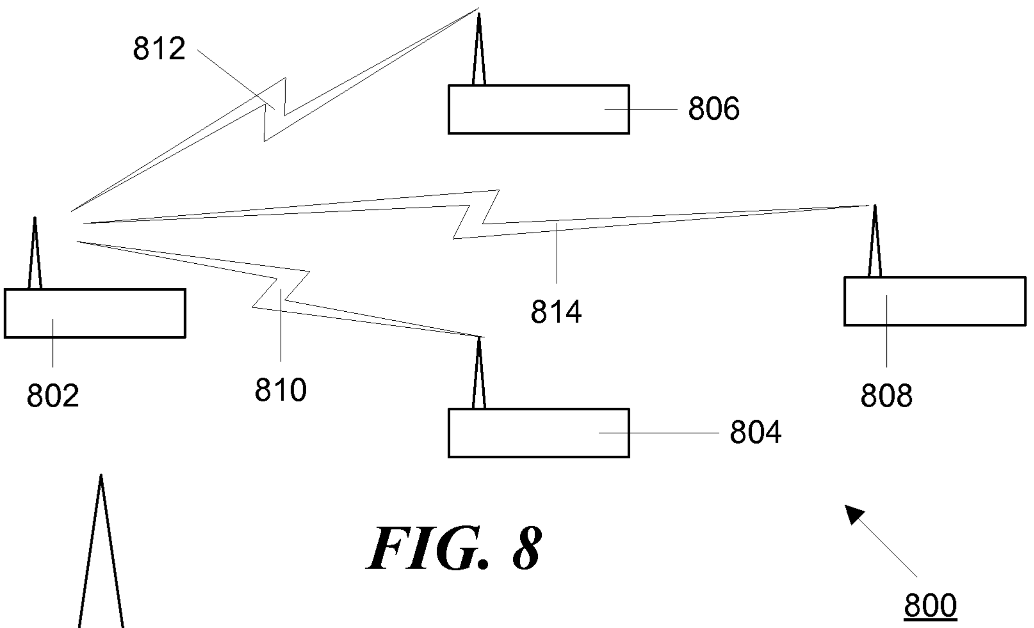


FIG. 8

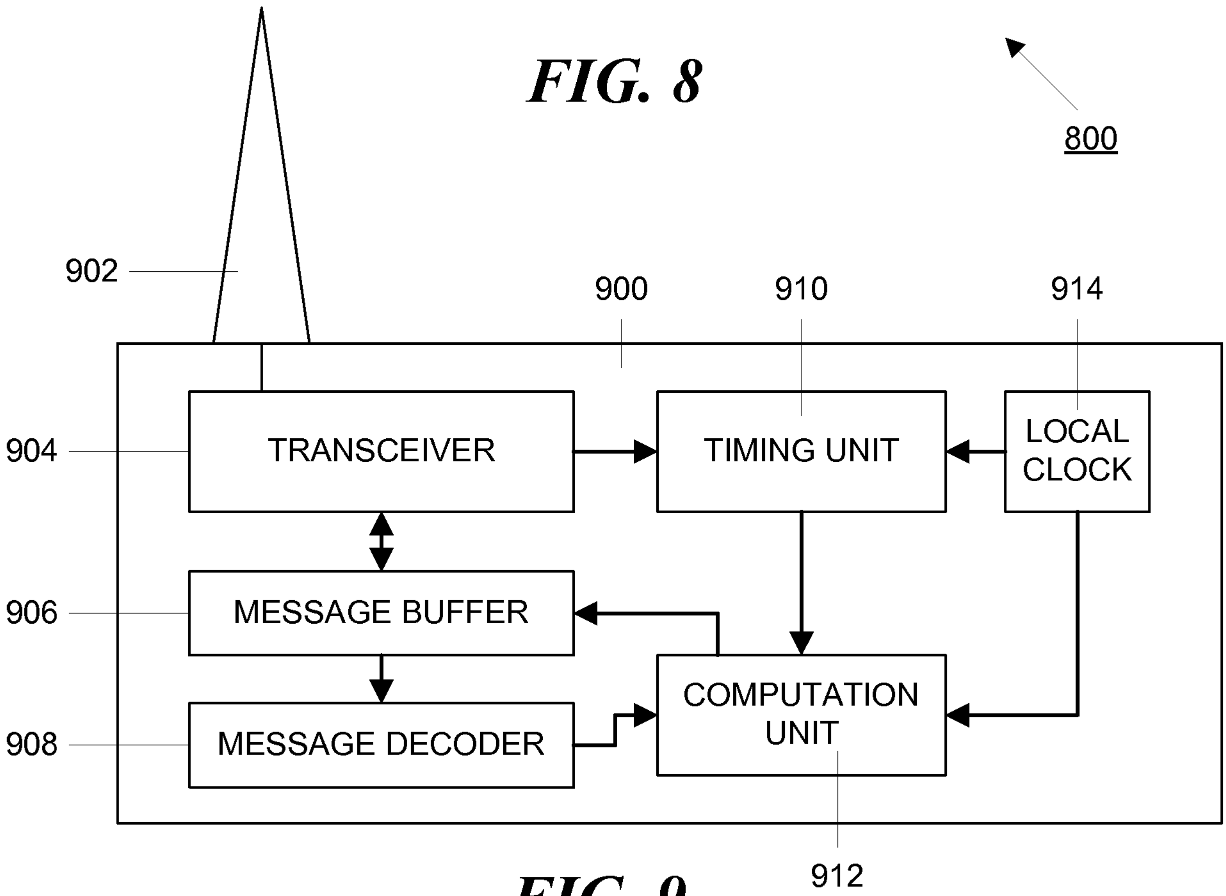


FIG. 9

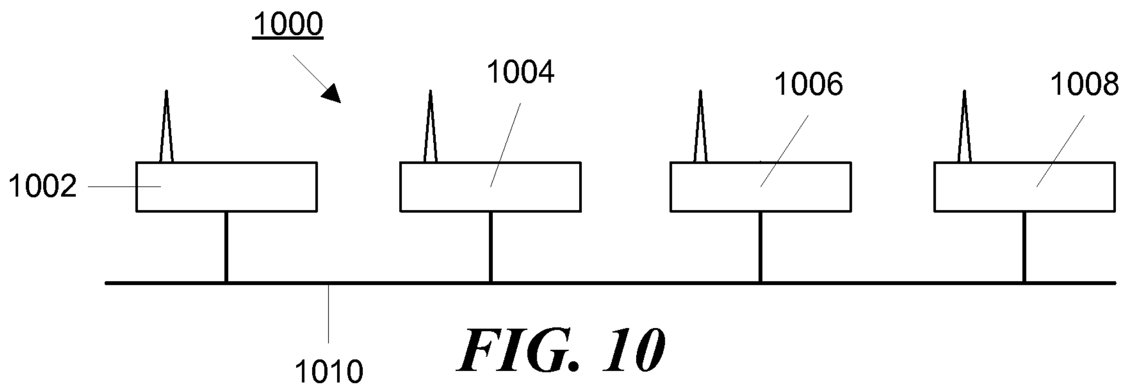


FIG. 10

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 08/72185

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - H04Q 7/20 (2008.04)
USPC - 455/456.1
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8): H04Q 7/20 (2008.04)
USPC: 455/456.1

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
IPC(8): H04Q 7/20 (2008.04)
USPC: 455/403, 455/404.2, 455/414.1, 455/414.2, 379/142.1, 379/201.06

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PubWest (USPB, USPT, USOC, EPAB, JPAB), DialogPro, GoogleScholar; time difference arrival computation location mobile device set base stations synchronizing local clock correction reception time timing signal message relative trilateration broadcast TOA subtract drift calibration quotient transceiver wireless network LAN WAN

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2006/0025158 A1 (Leblanc et al.), 02 February 2006 (02.02.2006), Figs. 1-3; para [0083]-[0086]; [0292]; [0299]; [0306]-[0307]; [0460]; [0465]-[0467]; [0476]-[0487]; [0494]; [0510]; [0514]-[0515]	1-19
Y	US 2007/0121560 A1 (Edge), 31 May 2007 (31.05.2007), para [0058]-[0060]; [0066]-[0070]; [0125]	1-19
A	US 2007/0155401 A1 (Ward et al.), 05 July 2007 (05.07.2007), entire document	1-19
A	US 2005/0288033 A1 (McNew et al.), 29 December 2005 (29.12.2005), entire document	1-19
A	US 2005/0192024 A1 (Sheynblat), 01 September 2005 (01.09.2005), entire document	1-19
A	US 2003/0222819 A1 (Karr et al.), 04 December 2003 (04.12.2003), entire document	1-19

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 October 2008 (15.10.2008)	22 OCT 2008

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